**TELKOMNIKA Telecommunication, Computing, Electronics and Control**
Vol. 18, No. 1, February 2020, pp. 456~464
ISSN: 1693-6930, accredited First Grade by Kemenristekdikti, Decree No: 21/E/KPT/2018
DOI: 10.12928/TELKOMNIKA.v18i1.11887 

# Improved backtracking search optimization algorithm for PV/Wind/FC system

**Jihane Kartite[1], Mohamed Cherkaoui[2]**
[1,2]Mohammed V University in Rabat, Agdal Rabat, Morocco
[2]Mohammedia School of Engineers, Morocco

**Article Info**

***Article history:***

Received Nov 24, 2018
Revised Aug 7, 2019
Accepted Aug 28, 2019

***Keywords:***

Fuel cell
IBSA
Optimization
Photovoltaic panel
Wind turbine

**ABSTRACT**

This paper uses a novel optimization method based on the improved backtracking search optimization algorithm (IBSA). The study is conducted for a hybrid stand-alone system composed of photovoltaic panel (PV), wind turbine generator and fuel cell electrolyzer (FC). To demonstrate the effectiveness of the IBSA, four benchmark functions are used. The result shows the better exploration and exploitation of the improved backtracking search optimization algorithm in terms of convergence and speed for system comprinsing PV panel wind, turbine generator and fuel cell. The proposed algorithm is used to optimize the annual total cost (ATC) of the energy produced and feed up the load demand. The economic evaluation of the Hybrid PV/Wind/FC system is done throughout hourly demand and daily wind speed and insulation. The simulation results justify the robustness of the IBSA.



***Corresponding Author:***

Jihane Kartite,
Mohammed V University in Rabat,
Agdal Rabat, Morocco.
Email: kartite.jihane@gmail.com

## 1. INTRODUCTION

The depletion of fossil fuels and the increasing energy demand over the world, about 55% by 2035 [1], are brought more attention to green energy. The production of electricity from conventional sources affects environment balance and causes pollution. This pollution affects lifes and animals. The power produced from fossil fuels gives off harmful gazes such as oxides of carbon. These gazes contribute to global warming. Limited reserves of fuels and their unstable costs are the most important reasons for renewable energy. The increasing concern about environmental pollution and the impact of traditional sources has emphasizes all countries for reducing their emission. Renewable energy sources seem to be the best solution for a sustainable electrification. We can have the electricity directly from sunlight via PV panel. Solar energy is one of the most promising renewable energy technologies: it is clean and abundance. However, the intermittent nature of these types of energy makes the energy produced from one renewable source unreliable [2, 3]. Coupling PV panel with another source of energy such as wind turbine generator can reduce significantly the intermittence issue.

The electric Hybrid renewable energy system is less costly and more reliable than system with one source [4, 5]. Designing a hybrid renewable energy system is a difficult task, the sizing or the number of element and the used control strategy is very essential, the performance of the PV/Wind/Fuel cell system can be significantly influenced by the proposed control strategy. Wind turbine generator and PV panel might operate in the way that they can give the maximum power to achieve a high efficiency value [6]. In this study, the photovoltaic (PV) panel and the wind turbine generator are used as the main source for the load demand.

the fuel cell (FC) electrolyzer is required as a storage capacity. The photovoltaic panel (PV) technology is seen as the easiest renewable source due to several reasons: The study of a hybrid renewable energy system (HRES) coupled with hydrogen energy is became an area of interest [7].

The traditional storage with chemical batteries provides high discharging efficiency and high energy storage capacity [8]. This system provides an improvement to overcome some drawbacks of RES especially the intermittence problem: the energy storage systems are able to feed load demand or consume the produced energy from renewable sources. Diesel generators or fuel cells seems necessary in hybrid renewable energy systems (HRES) by supplying the load demand when the storage facilities are enable or empty. The paper presents IBSA (improved backtracking search algorithm) to optimize the annual total cost (ATC) for photovoltaic generator, wind turbine generator and fuel cell system.

## 2. HYBRID RENEWABLE ENERGY SYSTEM PRESENTATION

The system used in this paper is a multisource system composed of hybrid renewable energy source system based on photovoltaic panel, wind turbine generator and fuel cells electrolyzer [9]. The storage facilities are used to smooth out the renewable energy fluctuation. Besides, storing electricity in large scale during off-peak hours reduce significantly the dependence of fossil energy during peak demand.

### 2.1. Photovoltaic (PV) panel model

To determine the power output for PV panel, two models are possible: the probabilistic one and the deterministic one. Both are based on climatic data. In this study we use the deterministic model to define the PV power. The electric power is determined directly from the nominal power of the PV cell. This power is injected directly in the DC bus:

$$E_{dirc} = E_{dir} \cdot \cos\theta \tag{1}$$

where Edirc is the direct sunlight received by the collector, θis the inclination angle.

$$E_{difc} = E_{dif} \cdot \left(\frac{1+\cos\theta}{2}\right) \tag{2}$$

Edifc is the diffuse sunlight received by the collector.

$$P_{pv} = \left(E_{dirc} + E_{difc}\right) \cdot \frac{P_{pvc}}{E_n} \tag{3}$$

Ppvc is the nominal power of PV panel and En is the insolation in standard conditions.

$$\cos\theta = \cos\beta \cdot \cos(\varphi s, \varphi c) + \sin\Sigma \cdot \sin\beta \cdot \cos\Sigma \tag{4}$$

β is the altitude of the sun, ϕsis the azimuth, ϕcis the collector azimuth and ∑ is the inclination angle of the solar collector.

$$\sin\beta = \cos L \cdot \cos\delta \cdot \cos H + \sin L \cdot \sin\delta \tag{5}$$

L is the latitude of the location, δ is the solar declination and H is the hour angle.

$$\sin\varphi s = \frac{\cos\delta \cdot \sin H}{\cos\beta} \tag{6}$$

### 2.2. Wind turbine model

Wind turbines use the kinetic energy of wind speed. In this paper the power delivered by wind turbine generator is modeled according to wind speed, as we can see in Figure 1. The power output of the wind turbine generator is based on wind speed. It is expressed by (7) as we can see in (7):

$$W = \begin{cases} 0, & v \prec v_d \\ \frac{1}{2} \cdot \rho \cdot \pi \cdot R^2 \cdot V^3, & v_d \leq v \prec v_n \\ P_n, & v_n \leq v \prec v_c \\ 0 & v \succ v_c \end{cases} \tag{7}$$

where Vd is the boot speed, Vn is the nominal speed and Vc is the shut down speed.

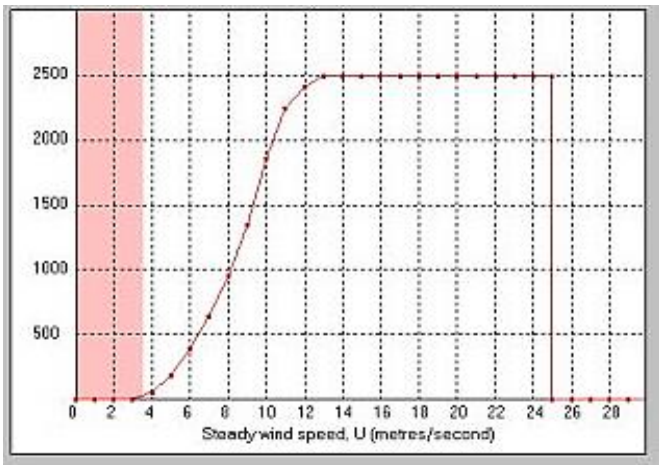



Figure 1. Wind turbine output power

### 2.3. Fuel cell model

There are different types of Fuel cell (FC); the most used for distributed generation is the proton exchange membrane (PEM) [10]. In this work, we consider PEM FC; it is studied by using the model of the FC stack. The output voltage of the FC Vfc can be calculated from the voltage developed inside the FC. It is expressed by the (8):

$$V_{fc} = E_{oc} - V_{act} - V_{ohm} \tag{8}$$

where Eoc is the voltage when the circuit is open, Vact is the intern voltage of the FC and Vohm is the ohmic voltage.

The number of hydrogen storage tanks is determined based on the Management strategy showed below:

– if the power generated from renewable energy sources (PV/Wind) is greater than the load demand, the electrolyser will be used to produce hydrogen. This hydrogen stored in the tanks can be calculated as follows:

$$E_{stor}(t) = E_{stor}(t-1) + (E_{ren}(t) - E_{load}(t)/Eff_{inv})Eff_{elect} \tag{9}$$

where Estor is the hydrogen stored in the tanks, Eren is the energy produced from renewable sources, Eload is the energy load and $Eff_{inv}$ is the efficiency of the inverter.

– when the energy demand of the load is greater than the energy produced by renewable energy sources, the FC will be used to feed up the load [11]. The amount of hydrogen stored in the tanks is calculated as (10).

$$E_{stor}(t) = E_{stor}(t-1) - \left(E_{load}(t) - E_{inv}(t)\right)/Eff_{fuel\_cell} \tag{10}$$

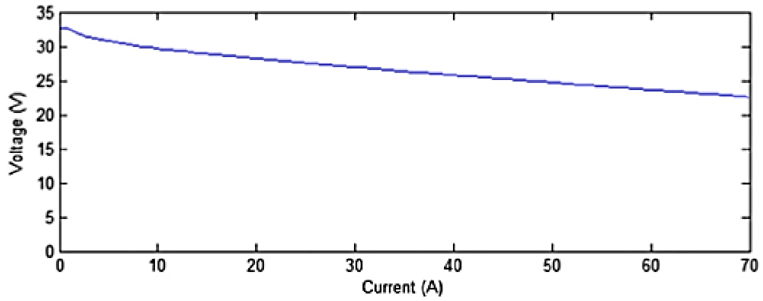
The cost of supplying the energy demand by FC electrolyzer is determined by the (11):

$$C_{SFC} = \frac{C_{FC}}{Life_{FC}} + C_{O\&M\_FC} \tag{11}$$

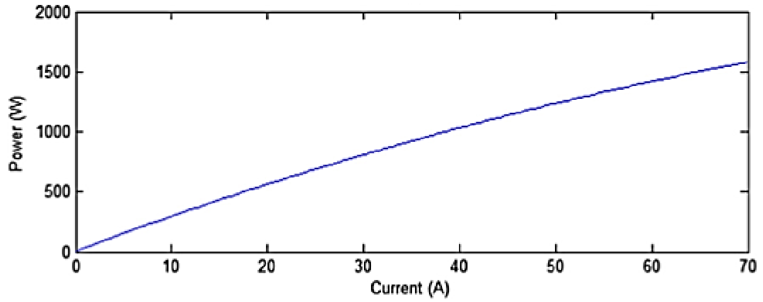
where $C_{FC}$ is the FC purchase cost, LifeFC is the FC lifetime and $C_{O\&M\_FC}$ are the FC operation and maintenance costs.

## 3. BACK-TRACKING SEARCH OPTIMIZATION ALGORITHM (BSA)

BSA is a methaheuristic algorithm, based on natural or biological evolutions techniques such as mutation. It is proposed to solve constrained optimization problems and overcome some drawbacks of the previous evolutionary algorithms: e.g., high sensitivity to the control parameter and time-consuming computation [12]. BSA's structure is simple; it has a powerful global exploration and local exploitation due to controlling the search direction by scale factor parameter [13, 14]. Figures 2 (a) and (b) shows power as a function of current and the voltage as a function of current for the FC used in this study. Figure 3 shows the general structure of the BSA algorithm. BSA has five main steps: initialization, selection-I, mutation, crossover and selection-II [15]. Its general structure is described in Figure 3. Figure 4 shows the initialization process of BSA.




(a)




(b)

Figure 2. (a) Power-current (b) Voltage-current curves of the FC

```
   Initialization
   Repeat
       Selection-I
Generation of trial population
          Mutation
          Crossover
      End
      Selection-II
Until stopping criteria are met
```

Figure 3. General structure of BSA

```
Initialization
if numel(low)==1, low=low*ones(1,dim);

up=up*ones(1,dim);

end
pop=GeneratePopulation(popsize,dim,low,up);
fitnesspop=feval(fnc,pop,mydata);
historical_pop=GeneratePopulation(popsize,dim,low,up);
```

Figure 4. BSA's initialization

– Initialization

In this process BSA generates the initial population by a uniform distribution.

– Selection-I

BSA defines the Old population Old P, which is used to calculate the search direction. The historical population is initialized by (12).

$$oldP_{i,j} = U\left(low_j, up_j\right) \tag{12}$$

In each iteration, BSA determine Old P by comparing two numbers generated randomly a and b. This comparison is shown in (13):

$$if\ a \prec b\ then\ oldP = P|a, b\ U(0,1)| \tag{13}$$

after determining the historical population Old P, BSA changes the order of individuals by using the permute function.

$$oldP = Permutting(oldP) \tag{14}$$

– Mutation

In this step BSA generates the initial form of trial population.

$$\text{Mutant} = P + F * (old\ P - P) \tag{15}$$

Where F is a function. Its value controls the amplitude of the search direction. It is expressed by (16):

$$F = 5 * randn, \text{ where } randn = N(0,1) \tag{16}$$

– Crossover

$$\begin{aligned} &Map_{i,rand(D)} = 1 \\ &Map_{i,u(1:[\cdot mixrate*rand*D])} = 1; u = permuting(1,2,3, \dots, D) \\ &Crossover = P + (map.* F).* (old\ P - P) \\ &T_{i,j} = rand * \left(up_j - low_j\right) + low_j \text{ if } T_{i,j} \text{ beyond the boundary.} \end{aligned} \tag{17}$$

– Selection

In this step, the individual with best fitness value is used to replace the previous individual.

## 4. IMPROVED BACKTRACKING SEARCH OPTIMIZATION ALGORITHM (IBSA)

BSA has a random strategy in defining mutation; the later introduces changes in individual position. The mix rate parameter (M) used in crossover operator controls the number of individuals that mutate in trial population. In this work the improved backtracking search optimization algorithm (IBSA) presented by [16] is used to study the impact of using a FC electrolyzer in a hybrid renewable energy system especially in terms of energy cost.

The IBSA is proposed to overcome some drawbacks of the traditional BSA such as the convergence issue [17-19]. However, BSA shows a strong robustness in finding the best cost value; its way in storing population from the previous generation may make it converge very slowly [20, 21]. The system used in this study is presented in Figure 5. It's composed of PV generator, wind turbine generator and Fuel cell system. The idea behind the IBSA is defining a new mutant based on the scale factor value. To see the effectiveness of the IBSA four benchmark functions are used as shown in Table 1. The simulation results are shown in Figure 6 and the statistics values are summarized in Table 2.

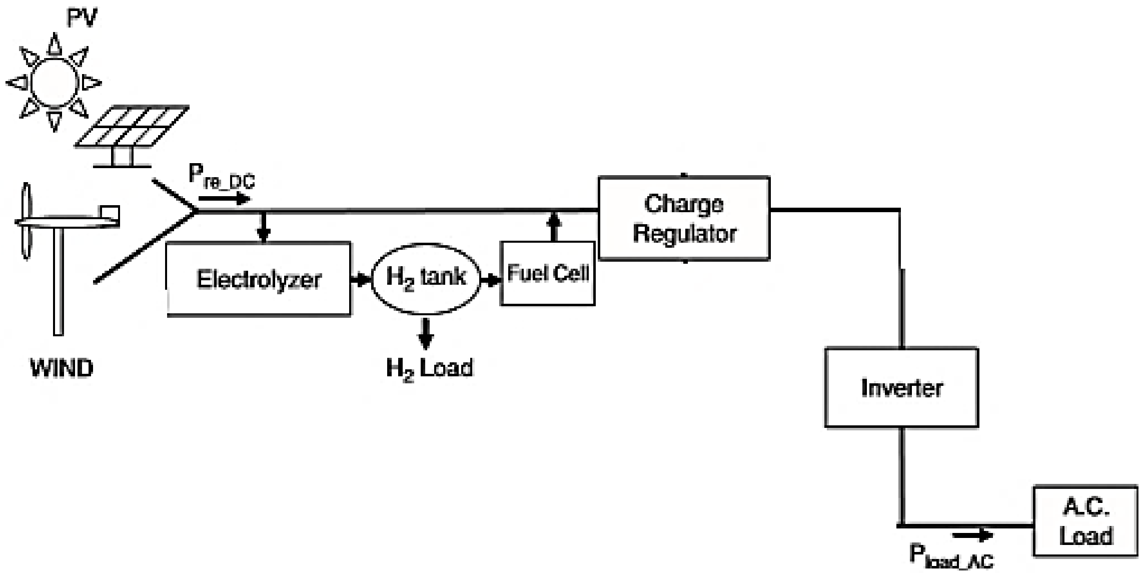



Figure 5. PV wind turbine generator fuel cell hybrid renewable system

Table 1. Low-up and dimension for the benchmark functions

| ID | Name | Low | Up | D |
|---|---|---|---|---|
| F1 | Ackley | -32 | 20.39 | 20,18 |
| F2 | Criewank | -600 | 0.2423 | 0.3449 |
| F3 | Schaffer | -100 | 20.24 | 19.63 |
| F4 | Shekel | -32 | 1.824 | 1.643 |

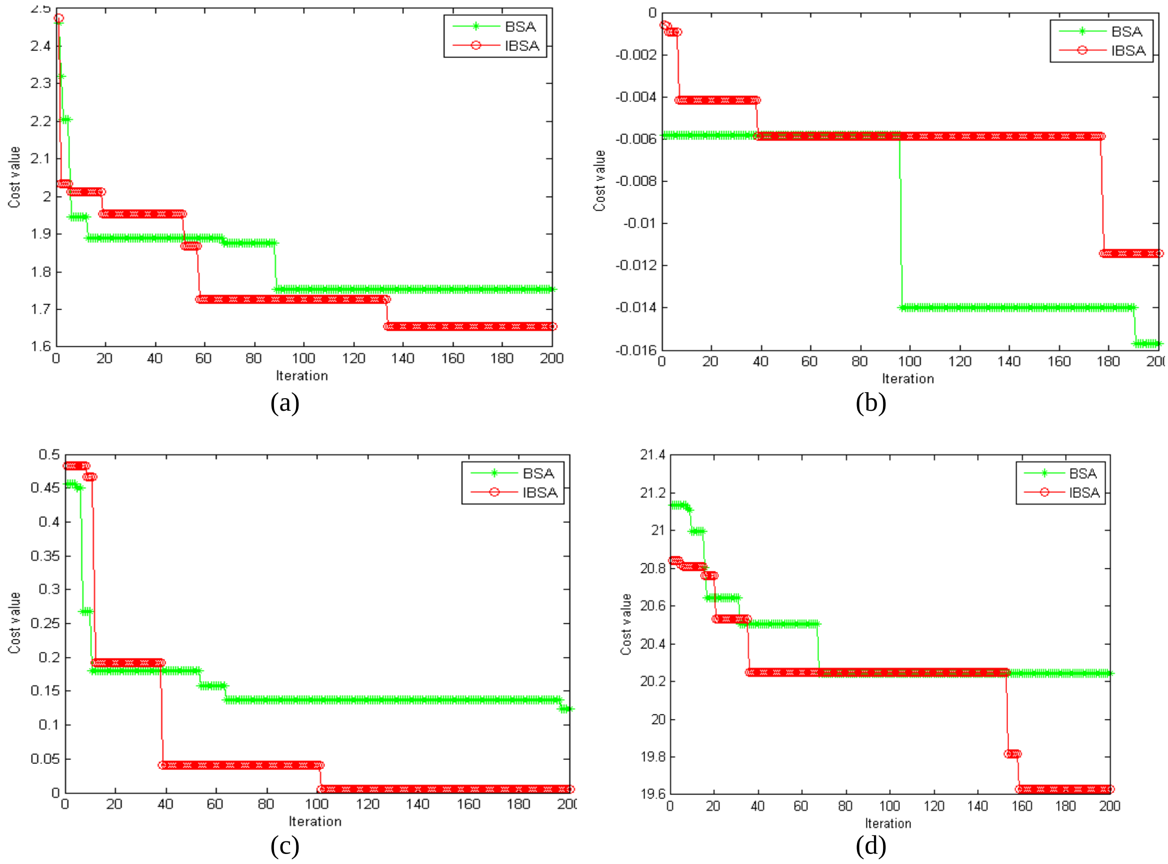



Figure 6. Optimal cost value for (a) F1, (b) F2, (c) F3 and (d) F4 using BSA (green curve) and IBSA (red curve)

### 4.1. Objective function

The ATC of the system can be defined as follows:

$$y1 = C_p^a . P_{pv} + C_w^a . W + C_{fc}^a . P_{fc} \quad (18)$$

where Cp is the total cost of PV generator, Cw is the total cost of wind turbine generator and Cfc is the total cost of the fuel cell. The cost of supplying energy with PV generator and wind turbine generator is determined in [22]. The cost of power produced from FC is determined in (19).

$$C_{SFC} = \frac{C_{FC}}{Life_{FC}} + C_{O\&M\_FC} \quad (19)$$

### 4.2. Electrolyzer model

The hydrogen production nh2 rate is determined based on Faraday's law [23], it is proportionnel to the electrical current inside the circuit [24]. The nh2 (mol/s) is determined in (20).

$$N_{H2} = \frac{n_F n_C i_e}{2F} \quad (20)$$

where $n_F$ is the Faraday efficiency, $n_C$ is the number of cells in series $i_e$ is the electrolyzer current and F is the Faraday constant.

## 5. SIMULATION AND RESULTS

The studied system is composed of PV generator, wind turbine generator and FC electrolyzer. The load demand is an AC load; and the inverter is used with an efficiency of 0.8. The FC is used to feed up the load in worse case for RE (renewable energy). The system flowchart is presented in Figure 5. The used system is composed of [25]:

- 6000 Wp PV generator, with a total acquisition cost of 40000 £.
- 5000 W wind turbine generator, with a total acquisition cost of 10000£ and an annual operation and maintenance cost of 300£.
- 1KW FC, acquisition cost of 4000£, O&M cost of 0.2£/h, 30000 h expected lifetime, Nfc = 16.66 KWh/KgH2 for the nominal power and Pmin = 60 W.
- 1KW electrolyzer, acquisition cost of 3200£, Neyz = 0.021KgH2/KWh.
- 0.1Kg H2 tank, acquisition cost of 150 £, O&M cost 10£/year, 25 years expected lifetime.

The main objective of this work is to size optimally a hybrid PV/Wind/FC system using IBSA and compare the result with the BSA. The proposed method aims to satisfy many requirements:

- Optimize the annual total cost (ATC) of the system.
- Demonstrate the effectiveness of the IBSA compared to the traditional BSA for system using Fuel cell.
- Study the influence of the electrolyzer current on the Faraday efficiency.

Table 1 and Table 2 show respectively the statistics values and the low-up and dimension for the benchmark functions.

Table 2. Statistics values for benchmark functions

| Problem | Statistics | BSA | IBSA |
|---|---|---|---|
| F1 | Mean | 20.39 | 20.18 |
| | Std | 0.2423 | 0.3449 |
| | Best | 20.24 | 19.63 |
| F2 | Mean | 1.824 | 1.643 |
| | Std | 0.1014 | 0.093 |
| | Best | 1.753 | 1.625 |
| F3 | Mean | 0.16 | 0.067 |
| | Std | 0.0573 | 0.1168 |
| | Best | 0.1241 | 0.0048 |
| F4 | Mean | -0.010 | -0.009 |
| | Std | 0.0041 | 0.002 |
| | Best | -0.015 | -0.011 |

### 5.1. Annual total cost optimization of hybrid system

Figure 5 shows the configuration of the Hybrid renewable PV/Wind/FC system under study. The proposed structure meets the power demand for isolated load located in Rabat, Morocco. Figure 6 plots the optimal value for the four benchmark functions for BSA and IBSA. In this work the PV generator and wind turbine generator are the primary energy source, while fuel cell electrolyzer is used as a backup system. The optimization method based on IBSA (improved backtracking search optimization algorithm) is used to size and design optimally the hybrid renewable energy system. The program is developed on MATLAB software. IBSA optimizes the numbers of PV panels (Npv), the numbers of wind turbines (Nw) and the numbers of FC electrolyzer (Nfc). These numbers are included in the power value of each component as shown in (18).

The IBSA must meet the load demand with a minimal cost value. The optimal annual total cost (ATC) is shown in Figure 7. The curve with green color is for BSA and the one with red color is for IBSA. To make a good comparison, we have maintained the same parameters for BSA and IBSA, i.e., population size and the number of generation. The simulation process is initialized by a random value of Npv, Nw and Nfc. It is demonstrated that the best ATC obtained by IBSA is better than the value obtained by BSA.

This work shows also the impact of the electrolyzer current on the Faraday efficiency Figure 8. The Faraday efficiency increases with the augmentation of the current that is means a high value for electrolyzer current gives a high level of efficiency. On the other hand, the renewable system has designed to feed up the load demand. This can be achieved through the electrolyzer current whish is directly linked to the produced hydrogen.

The level of hydrogen stored in the tank influences the optimization process (the value of ATC) and then the number of PV panels, the number of wind turbine and the number of FC. The number of PV panels Npv, the number of wind turbine generator Nw and the number of FC Nfc optimized by IBSA is shown in Figure 9. The optimal sizing and costs of the Hybrid PV/Wind/FC system is as follow:

- 6 KW of PV
- 5 KW of Wind
- 1 KW of FC

with an Annual Total Costs (ATC) of 14562.17 £.

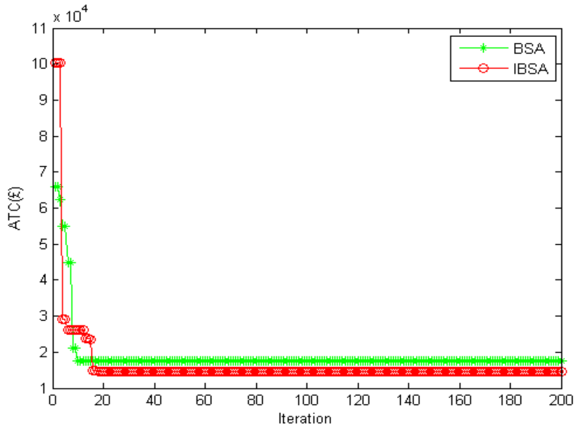



Figure 7. Optimal ATC with BSA (curve green) and IBSA (curve red)

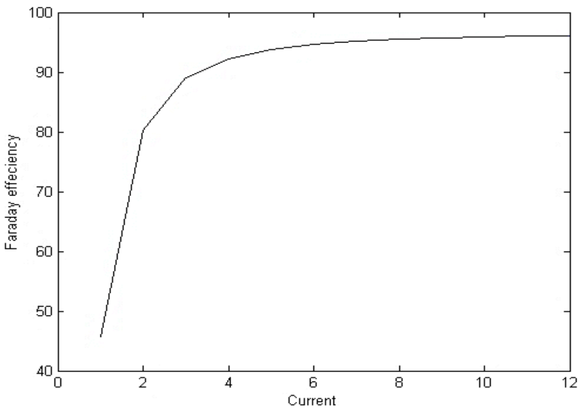



Figure 8. Faraday efficiency-current curve

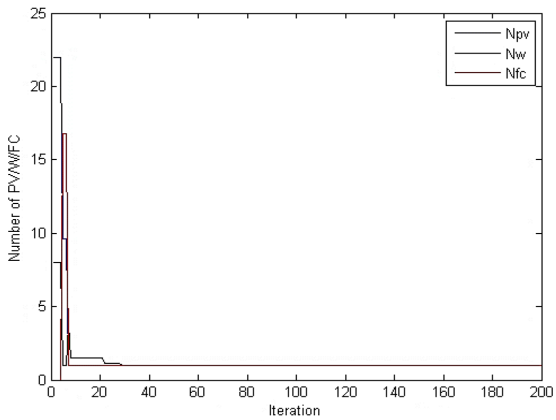



Figure 9. PV number/wind turbine/FC

## 6. CONCLUSION

This work has used a novel optimization method based on Improved backtracking search optimization algorithm (BSA). This is the first time when this new algorithm is used to perform a technical optimization for system compromising PV panels, wind turbine generators and fuel cell (FC). Firstly, a comparative study is done based on four benchmark functions: ackley, criewank, schaffer and schekel. The result shows the effectiveness of the IBSA and Table 1 summarizes the statistical value for the two compared algorithm BSA and IBSA. IBSA outperforms BSA in terms of convergence speed and best fitness value. Secondly, the system under study is modeled through several power equations then the objective function (OF) is defined. We have optimized the OF using BSA and IBSA, and it can be easily seen that the IBSA gives the best ATC value. Finally, we have concluded that the Faraday efficiency influences the electrolyzer current and so the hydrogen stored in the tank.

## REFERENCES

[1] Singh R. and Bansal R. C., "Review of HRESs based on storage options, system architecture and optimisation criteria and methodologies," *IET Renewable Power Generation*, vol. 12, no. 7, pp. 747-760, 2018.
[2] Adefarati T. and Bansal R. C., "Integration of renewable distributed generators into the distribution system: a review," *IET Renewable Power Generation*, vol. 10, no. 7, pp. 873-884, 2016.

[3] Castaneda M., et al., "Sizing optimization, dynamic modeling and energy management strategies of a stand-alone PV/hydrogen/battery-based hybrid system," *International journal of hydrogen energy*, vol. 38, no. 10, pp. 3830-3845, 2013.
[4] Dufo-Lopez R., et al., "Optimization of control strategies for stand-alone renewable energy systems with hydrogen storage," *Renewable energy*, vol. 32, no. 7, pp. 1102-1126, 2007.
[5] Bernal-Agustín J. L. and Dufo-Lopez R., "Simulation and optimization of stand-alone hybrid renewable energy systems," *Renewable and Sustainable Energy Reviews,* vol. 13, no.8, pp. 2111-2118, 2009.
[6] Basaran K., et al., "Energy management for on-grid and off-grid wind/PV and battery hybrid systems," *IET Renewable Power Generation*, vol. 11, no. 5, pp. 642-649, 2016.
[7] Castañeda, M., Fernández, L. M., Sánchez, H., Cano, A., & Jurado, F., "Sizing methods for stand-alone hybrid systems based on renewable energies and hydrogen," *2012 16th IEEE Mediterranean Electrotechnical Conference*, pp. 832-835, 2012.
[8] Cabrane Z., et al., "Battery and supercapacitor for photovoltaic energy storage: a fuzzy logic management," *IET Renewable Power Generation*, vol. 11, no. 8, pp. 1157-1165, 2017.
[9] Kartite J. and Cherkaoui M., "Optimization of hybrid renewable energy power systems using evolutionary algorithms," *5th International Conference Systems and Control (ICSC)*, pp. 383-388, 2016
[10] Wu W., et al., "Stabilised control strategy for PEM fuel cell and supercapacitor propulsion system for a city bus," *International Journal of Hydrogen Energy*, vol. 43, no. 27, pp. 12302-12313, 2018.
[11] Nelson D. B., et al., "Unit sizing and cost analysis of stand-alone hybrid wind/PV/fuel cell power generation systems," *Renewable energy*, vol. 31, no. 1, pp. 1641-1656, 2006.
[12] Civicioglu P., "Backtracking search optimization algorithm for numerical optimization problems," *Applied Mathematics and Computation*, vol. 219, pno. 15, pp. 8121-8144, 2013.
[13] Brévilliers M., et al., "Fast Hybrid BSA-DE-SA Algorithm on GPU," *International Conference on Swarm Intelligence Based Optimization*, Springer, Cham, pp. 75-86, 2016.
[14] Modiri-Delshad M and Rahim N. A., "Solving non-convex economic dispatch problem via backtracking search algorithm," *Energy*, vol. 77, pp. 372-381, 2014.
[15] El-Fergany A., "Optimal allocation of multi-type distributed generators using backtracking search optimization algorithm," *International Journal of Electrical Power & Energy Systems*, vol. 64, pp. 1197-1205, 2015.
[16] Kartite J. and Cherkaoui M., "Improved backtracking search algorithm for renewable energy system," *Energy Procedia*, vol. 141, pp. 126-130, 2017.
[17] Lin J., "Oppositional backtracking search optimization algorithm for parameter identification of hyperchaotic systems," *Nonlinear Dynamics*, vol. 80, no. 1-2, pp. 209-219, 2015.
[18] Duan H. and Luo Q., "Adaptive backtracking search algorithm for induction magnetometer optimization," *IEEE Transactions on Magnetics*, vol. 50, no. 12, pp. 1-6, 2014.
[19] Brévilliers, M., Abdelkafi, O., Lepagnot, J., & Idoumghar, L., "Idol-guided backtracking search optimization algorithm," *12th International Conference on Artificial Evolution (EA 2015)*, Lyon, France, 2015.
[20] Dubey H. M., et al., "Wind integrated multi area economic dispatch using backtracking search algorithm," *Power Systems (ICPS). 2016 IEEE 6th International Conference*, pp. 1-6, 2016
[21] Su Z., et al., "A hybrid backtracking search optimization algorithm for nonlinear optimal control problems with complex dynamic constraints," *Neurocomputing*, vol. 186, pp. 182-194, 2016.
[22] Kartite J. and Cherkaoui M., "Optimization of hybrid renewable energy power systems using evolutionary algorithms," *5th International Conference Systems and Control (ICSC)*, pp. 383-388, 2016.
[23] Castaneda M., et al., "Sizing optimization, dynamic modeling and energy management strategies of a stand-alone PV/hydrogen/battery-based hybrid system," *International journal of hydrogen energy*, vol. 38, no. 18, pp. 3830-3845, 2013.
[24] Khan M. J. and Iqbal M. T., "Dynamic modeling and simulation of a small wind–fuel cell hybrid energy system," *Renewable energy*, vol. 30, no. 3, pp. 421-439, 2005.
[25] Maleki A. and Askarzadeh A., "Optimal sizing of a PV/wind/diesel system with battery storage for electrification to an off-grid remote region: A case study of Rafsanjan, Iran," *Sustainable Energy Technologies and Assessments*, vol. 7, pp. 147-153, 2014.